DECLARATION

I, Dr. Kaoru MOTOYA, a national of Japan, 6th floor, Shinjukugyoen Bldg., 3-10, Shinjuku 2-chome, Shinjuku-ku, Tokyo 160-022, JAPAN do hereby solemnly and sincerely declare :

(1) THAT I am well acquainted with the Japanese language and English language, and

(2) THAT the attached is a full, true and faithful translation into the English language checked by me of true copy of Japanese Patent Application No. 2003-179726 filed in the Japanese Patent Office on June 24, 2003.

And, I, Dr. Kaoru MOTOYA, being sworn state that the fact set forth above are true.

Signed this 17th day of March, 2008

Kaoru Motoya

Dr. Kaoru MOTOYA

[NAME OF DOCUMENT] APPLICATION FOR PATENT
[REFERENCE NO.] P2271JST
[FILING DATE] June 24, 2003
[ADDRESSEE] DIRECTOR OF GENERAL OF THE PATENT OFFICE

[INVENTOR]
[ADDRESS] 4-4-22-32, Kamishinden, Toyonaka-shi, Osaka 560-0085 Japan
[NAME] Hideaki KASAI
[INVENTOR]
[ADDRESS] 22-10, Fujinosato-cho Takatsuki-shi, Osaka 569-0025 Japan
[NAME] Hiroshi NAKANISHI
[INVENTOR]
[ADDRESS] 3-8-17, Kosone-cho, Nishinomiya-shi, Hyogo 663-8122 japan
[NAME] Tomoya KISHI
[APPLICANT]
[CODE NUMBER] 396020800
[NAME] Japan Science and Technology Corporation
[AGENT]
[CODE NO.] 100082876
[PATENT ATTORNEY]
[NAME] Kazuyuki HIRAYAMA
[PHONE NO.] 03-3352-1808
[ELECTED AGENT]
[CODE NO.] 100069958
[PATENT ATTORNEY]
[NAME] Yasuzo KAIZU

[INDICATION OF FEE]
[REGISTER NO.] 031727
[AMOUNT] ¥21,000
[LIST OF ATTACHED DOCUMENTS]
[NAME OF DOCUMENT] SPECIFICATION 1
[NAME OF DOCUMENT] DRAWING 1

[NAME OF DOCUMENT] ABSTRACT 1
[GENERAL POWER OF ATTORNEY NUMBER] 0013677
[PROOF] NECESSARY

[Name of Document] SPECIFICATION
[Name of Invention] SURFACE-SPINTRONIC DEVICE
[Claims]

[Claim 1] A surface-spintronic spin conducting device, characterized in that it comprises a solid surface, a magnetic atom thin film layered on a surface of the solid crystal, and electrodes mounted at two locations on said magnetic atom thin film, whereby

a spin splitting surface electronic state band formed in a system comprising said solid crystal surface and said magnetic atom thin film is utilized to cause a spin current to flow.

[Claim 2] A surface-spintronic spin conducting device as set forth in claim 1, characterized in that said solid surface is a nonmagnetic solid surface having a surface projected bulk band gaps and said magnetic atom thin layer is a magnetic atom thin film having a thickness of one to several atom layers.

[Claim 3] A surface-spintronic spin conducting device as set forth in claim 2, characterized in that said nonmagnetic crystal surface is a copper (111) surface and said magnetic atom thin film is an iron atom thin film.

[Claim 4] A surface-spintronic spin switching device, characterized in that it comprises a solid crystal surface, a magnetic atom thin film layered on a surface of the solid crystal, electrodes disposed at two locations on said magnetic atom thin film, and a control means for controlling the direction of magnetization in said magnetic atom thin film, whereby

controlling, by said control means, the spin state of a spin splitting surface electronic state band formed in a system comprising said solid crystal surface and said magnetic atom thin film causes switching on and off a spin current of either a flow of electrons of up spin or a flow of electrons of down spin, of electrons supplied through one of said electrodes from an external spin conducting device.

[Claim 5] A surface-spintronic spin switching device as set forth in claim 4, characterized in that said solid surface is a surface of a nonmagnetic crystal having a surface projected bulk band gaps and said magnetic atom thin film is a magnetic atom thin film having a

thickness of one to several atom layers.

[Claim 6] A surface-spintronic spin switching device as set forth in claim 5, characterized in that said nonmagnetic crystal surface is a copper (111) surface and said magnetic atom thin film is an iron atom thin film.

[Claim 7] A surface-spintronic spin switching device as set forth in claim 4, characterized in that it has a control means including a conducting wire disposed laterally adjacent to said magnetic atom thin film and a means for passing an electric current through said conductor to generate around it a magnetic field that is utilized to change the direction of magnetization in said magnetic atom thin film.

[Claim 8] A surface-spintronic spin switching device as set forth in claim 4, characterized in that said means for controlling the direction of magnetization in said magnetic atom thin film includes:

an up spin and a down spin sources disposed laterally adjacent to said magnetic atom thin film;

a connection member connecting said up spin source to said magnetic atom thin film;

a connection member connecting said down spin source to said magnetic atom thin film;

a power supply for injecting spins of said up spin source and spins of said down spin source into said magnetic atom thin film, and further a means for applying a voltage from said power supply so as to inject spins of said up spin or down spin sources into said magnetic atom thin film, thereby switching its magnetization into a normal or reverse polarity direction.

[Claim 9] A surface-spintronic spin switching device as set forth in claim 8, characterized in that said up spin and down spin sources comprise ferromagnetic metals magnetized downwards and upwards, respectively, and each of said connection members comprises a nonmagnetic metal.

[Claim 10] A surface-spintronic spin memory device, characterized in that it comprises a solid surface, a magnetic atom thin film layered on a surface of the solid crystal, electrodes disposed at two locations

on said magnetic atom thin film, and a control means for controlling the direction of magnetization in said magnetic atom thin film, whereby controlling, by said control means, the spin state of a spin splitting surface electronic state band formed in a system comprising said solid surface and said magnetic atom thin film causes switching on and off a spin current of either a flow of electrons of up spin or a flow of electrons of down spin, of electrons supplied through one of said electrodes from an external spin conducting device, and wherein said magnetic atom thin film has a magnetization holding property that is utilized to store information.

[Claim 11] A surface-spintronic spin memory device as set forth in claim 10, characterized in that said solid crystal surface is a surface of a nonmagnetic crystal having a surface projected bulk band gaps, and said magnetic atom thin film is a magnetic atom thin film having a thickness of one to several atom layers.

[Claim 12] A surface-spintronic spin memory device as set forth in claim 11, characterized in that said nonmagnetic crystal surface is a copper (111) surface and said magnetic atom thin film is an iron atom thin film.

[Claim 13] A surface-spintronic spin memory device as set forth in claim 10, characterized in that it has a control means including a conducting wire disposed laterally adjacent to said magnetic thin film and a means for passing an electric current through said conductor to generate around it a magnetic field that is utilized to change the direction of magnetization in said magnetic atom thin film.

[Claim 14] A surface-spintronic spin memory device as set forth in claim 10, characterized in that said control means for controlling the direction of magnetization in said magnetic atom thin film includes:

an up spin and a down spin sources disposed laterally adjacent to said magnetic atom thin film;

a connection member connecting said up spin source to said magnetic atom thin film;

a connection member connecting said down spin source to said magnetic atom thin film;

a power supply for injecting spins of said up spin source and

spins of said down spin source into said magnetic atom thin film, and further a means for applying a voltage from said power supply so as to inject spins of said up spin or down spin source into said magnetic atom thin film, thereby switching its magnetization into a normal or reverse polarity direction.

[Claim 15] A surface-spintronic spin memory device as set forth in claim 14, characterized in that said up spin and down spin sources comprise ferromagnetic metals magnetized downwards and upwards, respectively, and each of said connection members comprises a nonmagnetic metal.

[Detailed Explanation of the Invention]

[0001]

[Technical Field]

The present invention relates to spintronic (spin electronic) devices and, more specifically, to a spin conducting, a spin switching, and a spin memory device.

[0002]

[Background Art]

Electronics has hitherto placed its basis on a charge of an electron. However, since an electron has a spin as its another attribute besides its charge and in recent years the limits of electronics placing its basis on the charge have begun to be seen, researches and developments have rapidly been put forward on spintronics, namely spin electronics, which is based on the spin of an electron.

For example, as a device utilizing a spin there is now a GMR (Giant Magneto Resistance) device, which has been put to practical use as a read-out device for magnetic hard disk memories, making it possible to achieve their present level storage capacity. There is also as a third-generation spintronic device a MRAM (Magneto Resistive Random Access Memory) using TMR (Tunnel Magneto Resistance) effect. The MRAM is being put to practical use as a next-generation nonvolatile memory that is low in power consumption, fast in reading and writing, and highly integrated.

[0003]

[Non-patent Reference 1]

Andrew Zangwil (Georgia Institute of technology), "Physics at Surface", Cambridge University press, New York, New Rochelle Melbourne Sydney.

[Non-patent Reference 2]

H. C. Manoharan, C. P. Lutz & D. M. Eigler, "Quantum mirages formed by coherent projection of electronic structure", Nature, Vol. 403, pp. 512 – 515, 2000

[Non-patent Reference 3]

Takeo Fujiwara, "Kotai Denshi Kouzou (Solid Electron Structure)", Asakura Shoten, Chapter 3

[Non-patent Reference 4]

J. Shen, J. P. Pierce, E. W. Plummer & J. Kirschner, "The effect of spatial confinement on magnetism: films, stripes and dots of Fe on Cu (111)", JOURNAL OF PHYSICS: Condensed Matter, Vol. 15, R1 – R30, 2003

[0004]

[Problems to be Solved]

In the spintronics, however, there have not yet been realized a conductor for passing a spin current (spin-polarized current) and a switch for turning on and off a spin current, which are corresponding to an electric current conductor and an electric current switch such as FET, respectively. For example, while it has been proposed to utilize spin-injection from a ferromagnetic metal into a semiconductor, a problem of losing spin information upon the spin-injection remains unsolved and the prospect of its utilization can not still be foreseen.

[0005] In view of the problem mentioned above, the present invention has for its objects to provide a surface-spintronic spin conducting device that is capable of flowing a spin current based on a novel principle of operation, to provide a surface-spintronic spin switching device that is capable of switching a spin current with low power consumption, rapidly and efficiently, and to provide a surface-spintronic spin memory device utilizing the same.

[0006]

[Means to Solve Problems]

In order to achieve an object as mentioned above, there is provided in accordance with the present invention a surface-spintronic spin conducting device, characterized in that it comprises a solid surface, a magnetic atom thin film layered on a surface of the solid crystal, and electrodes mounted at two locations on said magnetic atom thin film, whereby a spin splitting surface electronic state band formed in a system comprising said solid crystal surface and said magnetic atom thin film is utilized to cause a spin current to flow. The solid surface is preferably a nonmagnetic solid surface having surface projected bulk band gaps, which is preferably, e.g., a copper (111) surface and the magnetic atom thin film is a magnetic atom thin film having one to several atomic layers in thickness, e. g., of iron atoms.

[0007] According to the makeup mentioned above, a direction of magnetization of the magnetic atom thin film determines a spin orientation that can contribute to conduction in the surface electronic state band, and the surface-spintronic spin conducting device thus provided causes only a spin current of which the spin is so oriented.

[0008] And, if electrons consisting only of up spin or electrons consisting only of down spin are supplied from the electrode using the spin conducting device, a spin current flows when the spin orientation of supplied electrons coincides with that of the surface electronic state band and no spin current flows when that is not the case. By controlling the direction of magnetization in the magnetic atom thin film, it is possible to make the spin orientation in the surface electronic state band coincident or not coincident with the spin orientation of the supplied electrons, and for this reason, it is possible to switch a spin current on and off and to realize a spin switching device. The surface electronic state band that can contribute to conduction can be made either of up spin only electronic state or down spin only electronic state, therefore it is possible to switch a spin current on and off at an efficiency of 100 %. Also said spin conducting device can be used as a unit element for spintronic logic circuit and as a magnetoresistance element having an infinite changing rate of

resistance. And also, it can be used as a spin memory device, because a magnetization direction of the magnetic atom thin film, which is once controlled in one direction, remains held until next magnetization direction controlling is applied.

[0009] The surface-spintronic spin switching device and the surface-spintronic spin memory device in accordance with the present invention are constituted as described below for controlling the direction of magnetization in the magnetic atom thin film.

Namely, the surface-spintronic spin switching device and the surface-spintronic spin memory device may be characterized in that it includes, as a form of implementation, a conducting wire disposed laterally adjacent to the magnetic atom thin film and a means for passing an electric current through the conductor to generate around it a magnetic field that is utilized to change the direction of magnetization in the magnetic atom thin film normal or reverse.

An alternative form of implementation may be characterized by including an up spin and a down spin source disposed laterally adjacent to the magnetic atom thin film; a connection member connecting the up spin source to the magnetic atom thin film; a connection member connecting the down spin source to the magnetic atom thin film; a power supply for injecting spins of the up spin source or spins of the down spin source into the magnetic atom thin film, wherein by applying a voltage of the power supply so as to inject spins of the up spin source or down spin source into the magnetic atom thin film, its magnetization direction is changed into normal or reverse direction. Preferably, the up spin source and down spin source comprise of ferromagnetic metals magnetized upwards and downwards respectively, and each of the connection members comprises of a nonmagnetic metals.

[0010] According to the makeup mentioned above, it is possible to magnetize the magnetic atom thin film controllably in a desired direction and as a result to switch a spin current on and off. Further, a surface-spintronic device according to the present invention, which utilizes a surface electronic state band formed in a system comprising a solid surface and a magnetic atom thin film, can confine a spin

current into an extremely small space and, as a result, can be made extremely small. Further, in switching a spin current on and off, the device only requires switching the spin orientation in the magnetic atom thin film made of one to several atomic layers, normally and reversely. Hence, the required energy is extremely small and there is realized an ultimate energy saving performance.

[0011]

[Modes for Carrying Out the Invention]

Hereinafter, the suitable forms of implementation of the present invention is explained. In this connection, all the factors required for carrying out the invention except for the factors specifically referred to in the present specification can be recognized as the design items of persons skilled in the art based on prior arts. The present invention can be carried out based upon the disclosed items by the present specification and drawings hereof and upon the technological commonsense in the corresponding fields.

[0012] Now, to facilitate understanding of the present invention, an explanation is given in detail of a surface-spintronic spin conducting device. Mention is made of spin split surface electronic state bands formed in a magnetic atom thin film layered on a solid surface. Although here, for example, the solid surface is shown as a copper (111) surface and a magnetic atom thin film as an iron monoatomic layer thin film, it should be understood that this is not a limitation.

However, it is not intended that a surface-spintronic device according to the present invention be limited to the makeup described below, and any spintronic device that utilizes a spin split surface electronic state band should be taken to fall within the present invention.

[0013] Fig. 1 (a) is a graph illustrating surface electronic state bands of a copper (111) surface (see Non-patent Reference 1.). In the graph, the abscissa axis represents the wave number towards point M from point Γ in the surface plane and the ordinate axis represents the electronic state energy. In Fig. 1(b), the hexagon shown represents the Brillouin zone of the copper (111) surface and

characters Γ, M and K indicate directions of the wave number vector of the graph in a wave number space.

In Fig. 1(a), the shaded area represents a projection of the band structure of a copper bulk crystal onto the (111) surface and indicates that an electronic state continuously exists in this area of wave number and energy. If there exists an electron in this shaded area, then the electron will diffuse into the bulk crystal. Each area unshaded is called the surface projected bulk band gap, indicating that an electron having a wave number and energy that fall in the area cannot exist in the bulk crystal.

The broken lines represent surface electronic state bands of the copper (111) surface, and especially, the surface electronic state band of the broken line located in the surface projection gap has a surface electronic state which has no intersection with any electronic state of the bulk crystal having the corresponding wave number and energy, thus causing an electron having those wave number and energy to remain localized having an atomic scale on the surface. Indeed, such a surface localized state has been confirmed to exist (see Non-patent Reference 2.), and the present invention utilizes such energy states of electrons which can propagate through the surface.

[0014] Fig. 2 is a graph illustrating first principle calculation results of the band structure of a system in which one layer of iron atomic thin film was laid on a copper (111) surface by the present inventors.

The first principle calculation is a computational technique based on the density functional theory showing that "the energy of the ground state of an interacting many-electron system is determined by the density distribution of electrons" (see Non-patent Reference 3.). The first principle calculation makes it possible to discuss the electronic structure of a material quantitatively without an extra empirical parameter and, indeed, its effectiveness has been proved by a number of examples. In this calculation, the generalized gradient approximation is applied, of which the accuracy is now the highest in the first principle calculation.

[0015] In the figure, the curves indicated with marks◆represent

majority spin electron band while the curves indicated with marks □ represent minority spin electron bands. In a system containing electrons each of which has up spin and electrons each of which has down spin, the majority spin means the spin which a larger number of such electrons have and the minority spin means the spin which a smaller number of such electrons have. Thus, the spin orientation of the whole, which is determined by their total, is equal to the orientation of the majority spin. And, if a contribution of the orbital magnetic moment is small, then the direction of magnetization is opposite to the spin orientation of the whole, then the direction of magnetization is equal to the orientation of the minority spin. Of electronic state bands as shown, two surface electronic state bands of minority spin S1 and S2 are indicated with solid circles and two surface electronic state bands of majority spin S3 and S4 are indicated with broken circles. The surface electronic state band of minority spin refers to a surface electronic state band having the minority spin localized in an atomic scale on the vicinity of a magnetic atom thin film and oriented perpendicular thereto. Likewise, the surface electronic state band of majority spin here refers to a surface electronic state band having the majority spin localized in an atomic scale on the vicinity of a magnetic atom thin film and oriented perpendicular thereto.

[0016] As shown in the figure, a majority spin electronic state and a minority spin electronic state differ in energy, whereby spin splitting occurs in this system. Also a minority spin surface electronic state bands S1, S2 and a majority spin surface electronic state bands S3, S4 are formed in different energy regions, whereby spin splitting occurs for surface electronic bands. Of them, S1, S2 which exist in a surface projected bulk band gap can be utilized as an energy state for an electron propagating through a surface.

Thus, the minority spin surface electronic state band S1 or S2 in the surface projected bulk band gap can be utilized to pass through a surface a spin current consisting only of spins of electrons capable of occupying that state.

Note here that which of up spin or down spin is a spin of an

electron occupying the minority spin surface electronic state band S1 or S2 is determined by a direction of magnetization in the magnetic atom thin film.

[0017] An iron atom thin film that is of one or two atomic layers in thickness has its easy axis of magnetization perpendicular to its surface and magnetized upwards or downwards with respect thereto (see Non-patent Reference 4.). When the magnetization of an iron atom thin film is oriented upwards (then, the majority spin is the down spin and the minority spin is the up spin; this state is termed as a "normally polarized" state), the minority spin surface electronic bands S1 and S2 can be occupied with electrons exclusively of up spin. To wit, the electrons which can be injected into S1 or S2 and are allowed to propagate through the surface are electrons exclusively of up spin. On the other hand, when the magnetization of an iron atom thin film is oriented downwards (then, the majority spin is the up spin and the minority spin is the down spin; this state is termed as a "reversely polarized" state), S1 and S2 can be occupied with electrons exclusively of down spin. To wit, the electrons which can be injected into S1 or S2 and are allowed to propagate through the surface are electrons exclusively of down spin.

[0018] This can be utilized to pass either a stream of electrons of up spin or a stream of electrons of down spin (A flow of perfect spin polarized current, namely a spin current, can be passed through the surface.).

Referring next to Fig. 3, an explanation is now given in respect of a suitable form of implementation of the surface-spintronic spin conducting device in accordance with the present invention. In Fig. 3, the spin conducting device, designated by reference character 10, is shown comprising a substrate 11, a solid crystal 12, a magnetic atom thin film 13 and a pair of electrodes as a drain and a source electrode 14 and 15, respectively.

[0019] The substrate 11 supports the solid crystal 12 formed thereon and is made of an insulating material which should, preferably but not exclusively, be aluminum oxide or the like, when the solid crystal is copper.

[0020] The magnetic atom thin film 13 is formed on a surface of the solid crystal 12 having a surface projected bulk band gap so that it has a film thickness of one or several atom layers, and this system has spin splitting surface electronic state bands (S1, S2) that exist in the surface projected bulk band gap.

Note here that though the magnetic atom thin film 13 is depicted to be rectangular, it may take any desired pattern to form a given spin current circuit in the spintronics just as a pattern to form an integrated circuit in the conventional electronics.

[0021] The drain and source electrodes 14 and 15 are mounted at two locations, respectively, on the magnetic atom thin film. Although the electrodes are each illustratively shown in the form of a probe for a scanning tunneling microscope (STM) for contact with the magnetic atom thin film, the contact may be by way of tunneling contact as in the ordinary use of STM as shown, namely by bringing the probe near the magnetic atom thin film surface to bring into point contact therewith, or otherwise by the usual way of sticking each electrode to the surface to establish facial contact therewith. By applying a bias voltage corresponding in energy to a surface electronic state band between the magnetic atom thin film 13 and the source electrode 15, it is possible to inject from the source electrode 15 into the thin film 13 those electrons selectively, whose spin is identical in orientation to the spin of electrons in the surface electronic state band. Electrons so injected are taken out at the drain electrode 14 which is higher in electric potential than the source electrode 15. In this way, electrons whose spin is identical in orientation to the spin of the surface electronic state band are caused to flow from the source electrode 15 through the magnetic atom thin film 13 to the drain electrode 14.

[0022] Thus, with the system of a magnetic atom thin film on a solid surface, a perfect spin-polarized electron current, namely spin conducting device is made possible, wherein either a flow of electrons of up spin or a flow of electrons of down spin is selectively conducted. In this way, the surface-spintronic spin conducting device 10 can be caused to function as a spin conductor. Moreover, since the spin direction of an electron to be conducted can be determined by the

direction of magnetization in the magnetic atom thin film, if electrons being fed from the source electrode 15 are perfectly spin polarized beforehand by another surface-spintronic spin conducting device, or the like, it is possible to switch the conduction of a spin current on and off by magnetizing the magnetic atom thin film in the normal or the reverse directions.

[0023] Referring next to Fig. 4, an explanation is now given in respect of a suitable form of implementation of the surface-spintronic spin switching device in accordance with the present invention. Being a surface-spintronic device, the spin switching element shown designated by reference character 16 in Fig. 4 incorporates a first mechanism for magnetizing the magnetic atom thin film in the normal and reverse directions, which as a magnetization switching means 20 is added to the makeup of the surface-spintronic spin conducting device 10 described above.

[0024] The first magnetization switching means comprises two electric current lines 21 and 22, a power supply 23 for these current lines 21 and 22, and two switches 24 and 25 for passing individual electric currents through the electric current lines 21 and 22 from the power supply 23, respectively.

[0025] The current lines 21 and 22, the magnetic atom thin film 13 and the power supply 23 are arranged and configured so that a magnetic field generated when the electric current line 21 or 22 has the electric current flow therethrough has on the magnetic atom thin film 13 a component parallel to its easy axis of magnetization and the magnetic field generated by the electric current flow through the electric current line 21 is oriented opposite to that generated by the electric current flow through the electric current line 22. While as shown the electric current lines 21 and 22 are disposed on each other side of the magnetic atom thin film 13 and laid parallel to each other to carry the respective current to flow in the same direction, this is not a limitation.

[0026] The switch 24 is a switch for normally polarized magnetization that can be turned on to cause the current to flow through the current line 21 from the power supply 23 while the switch

25 is a switch for reversely polarized magnetization that can be turned on to cause the current to flow through the current line 22 from the power supply 23.

[0027] In the surface-spintronic spin switching device 16 with the first magnetization switching means constructed as mentioned above, the electric current is passed to flow though the current line 21 from the power supply 23 when the switch 24 is turned on. This state is illustrated in Fig. 5(A), which depicts a magnetic field distribution in a cross section perpendicular to the current line 21 and from which it is seen that an upward magnetic field H1 is applied onto the magnetic atom thin film 13 to magnetize it upwards. Thereafter, even with the switch 24 turned off, the magnetic atom thin film 13 by its magnetization holding property remains magnetized upwards, thus retaining the normally polarized state of magnetization.

Therefore, once the switch 24 is turned on, only electrons of up spin can propagate from the source electrode 15 to the drain electrode 14 through the surface electronic state band of the magnetic atom thin film 13. The surface-spintronic spin switching device 16 is rendered conductive when only electrons of up spin are supplied from the source electrode 15. The surface-spintronic spin switching device 16 is rendered nonconductive when only electrons of down spin are supplied from the source electrode 15.

[0028] Then, if the switch 24 is turned off and the switch 25 is turned on, the electric current flows through the electric current line 22 from the power supply 23. This state is illustrated in Fig. 5(B), which depicts a magnetic field distribution in a cross section perpendicular to the electric current line 22 and from which it is seen that a downward magnetic field H2 is applied onto the magnetic atom thin film 13 to magnetize it downwards. Thereafter, even with the switch 25 turned off, the magnetic atom thin film 13 by its magnetization holding property remains magnetized downwards, thus retaining the reversely polarized state of magnetization.

Therefore, once the switch 25 is turned on, only electrons of down spin can propagate from the source electrode 15 to the drain electrode 14 through the surface electronic state band of the magnetic

atom thin film 13. The surface-spintronic spin switching device 16 is rendered nonconductive when only electrons of up spin are supplied from the source electrode 15. The surface-spintronic spin switching device 16 is rendered conductive when only electrons of down spin are supplied from the source electrode 15.

[0029] When from this state the switch 24 is again turned on, the magnetization of the magnetic atom thin film is switched again into the normal polarity direction so that the surface-spintronic spin switching device 16 can conduct only electrons of up spin. Thus, supplied only with electrons of up spin from the source electrode 15, the surface-spintronic spin switching device 16 is rendered conductive. Supplied only with electrons of down spin from the source electrode 15, the surface-spintronic spin switching device 16 is rendered nonconductive.

In this way, the surface-spintronic spin switching device 16 functions as a spin switching device which is caused to switch its conductive and nonconductive states for a spin current when the direction of its magnetization is switched by the control means.

[0030] Fig. 6 shows a surface-spintronic spin switching device 17, which incorporates a second mechanism as the magnetic polarity switching means. The surface-spintronic spin switching device 17 is constructed having the second magnetic polarity switching means added to the surface-spintronic spin conducting device 10.

The second magnetic polarity switching means comprises two spin sources 31 and 32 which are magnetized parallel to an easy axis of magnetization of the magnetic atom thin film 13 and in mutually opposite direction; two connections 31a and 32a that connect the magnetic atom thin film 13 to the two spin sources 31 and 32, respectively; a power supply 33 for providing a bias voltage for magnetization spin injection; and two switches 34 and 35 for it.

[0031] The spin sources 31 and 32 are made of ferromagnetic metals which are magnetized in the same directions identical to the directions of magnetization in which the magnetic atom thin film 13 is to be normally and reversely magnetized, respectively. Advantageously but not exclusively, the spin sources 31 and 32 are

the ferromagnetic metals magnetized upwards and downwards directed perpendicular to their surfaces, respectively, when the solid surface 12 is a copper (111) surface and the magnetic atom thin layer 13 is an iron monoatomic thin film.

Further, for spin injection by applying a bias voltage between the spin source 31 or 32 and the magnetic atom thin layer 13, the spin sources 31 and 32 are connected to the magnetic atom thin film via the connection members 31a and 32a, respectively. The connection members 31a and 32a may be sufficient if they permit spin injection from the corresponding spin sources 31 and 32 into the magnetic atom thin film 13 but are preferably made of nonmagnetic and electrically conductive material whose lattice constant is close to those of the atomic thin film 13 and the spin sources 31 and 32.

[0032] The switch 34 is a switch for normally polarized magnetization that can be turned on to apply a bias voltage of a selected magnitude from the power supply 33 between the spin source 31 and the magnetic atom thin film 13.

And, the switch 35 is a switch for reversely polarized magnetization that can be turned on to apply a bias voltage of a selected magnitude between the spin source 32 and the magnetic atom thin film 13.

[0033] In the surface-spintronic spin switching device 17 with the second magnetic polarity switching means constructed as mentioned above, turning the switch 34 on causes the bias voltage to be applied between the spin source 31 and the magnetic atom thin film 13 and normally polarized spins to be injected into the magnetic atom thin film 13 from the spin source 31, thereby magnetizing the magnetic atom thin film 13 in the normal direction. Thereafter, even with the switch 34 turned off, the magnetic atom thin film 13 by its magnetization holding property remains in the state of magnetization in the normal direction.

Therefore, once the switch 34 is turned on, only electrons of up spin can propagate from the source electrode 15 to the drain electrode 14 through the surface electronic state band of the magnetic atom thin film 13. The surface-spintronic spin switching device 17 is

rendered conductive when only electrons of up spin are supplied from the source electrode 15. The surface-spintronic spin switching device 17 is rendered nonconductive when only electrons of down spin are supplied from the source electrode 15.

[0034] After the switch 34 is turned off, if the switch 35 is turned on, the bias voltage is applied between the spin source 33 and the magnetic atom thin film 13 to inject reversely polarized spins into the magnetic atom thin film 13 from the spin source 33. This causes the magnetic atom thin film 13 to be magnetized in the reverse direction. Thereafter, even with the switch 35 turned off, the magnetic atom thin film 13 by its magnetization holding property remains in the state of magnetization in the reverse direction.

Therefore, once the switch 35 is turned on, only electrons of down spin can flow from the source electrode 15 to the drain electrode 14 through the surface electronic state band on the magnetic atom thin film 13. The surface-spintronic spin switching device 17 is rendered conductive when only electrons of down spin are supplied from the source electrode 15. The surface-spintronic spin switching device 17 is rendered nonconductive when only electrons of up spin are supplied from the source electrode 15.

[0035] After the switch 35 is turned off, if the switch 34 is again turned on, the magnetization of the magnetic atom thin film 13 is switched again into the normal polarity direction so that the surface-spintronic spin switching device 17 can conduct only electrons of up spin. Thus, supplied only with electrons of up spin from the source electrode 15, the surface-spintronic spin switching device 17 is rendered conductive. Supplied only with electrons of down spin from the source electrode 15, the surface-spintronic spin switching device 17 is rendered nonconductive.

In this way, the surface-spintronic spin switching device 17 functions as a spin switching device which is caused to switch its conductive and nonconductive states for a spin current when the polarity of its magnetization is switched by normally and reversely polarizing spin injections effected by the second control means.

[0036] While each of the surface-spintronic spin switching device

16 and 17 has been shown and described as functioning as a spin switching device that is controllably rendered conductive and nonconductive for a spin current propagating through the magnetic atom thin film, this is not their exclusive use but they can also be used as a surface-spintronic spin memory device using the fact that once the element is switched to a normally or reversely magnetized state, it can retain that state in the magnetic atom thin film until it is switched to the reversely or normally magnetized polarity state. To wit, it is possible to use a direction of magnetization as storage information, to use the magnetization switching means to perform the operation of writing the information, and to detect the state of conduction or nonconduction between the source and drain electrodes 15 and 14 for a spin current to perform the operation of reading the information.

[0037] Although the present invention has hereinbefore been set forth with respect to certain illustrative embodiments thereof, it will readily be appreciated to be obvious to those skilled in the art that many alterations thereof, omissions therefrom and additions thereto can be made without departing from the essences of scope of the present invention. Accordingly, it should be understood that the invention is not intended to be limited to the specific embodiments thereof set forth above, but to include all possible embodiments that can be made within the scope with respect to the features specifically set forth in the appended claims and to encompass all the equivalents thereof.

[0038]

[Industrial Applicability]

To establish a state of electrons that bear conduction, a surface-spintronic device according to the present invention utilizes a spin splitting surface electronic state band formed in a system comprised of a solid surface and a magnetic atom thin film layered thereon. Thus, a spin conducting device is realized that can carry a perfect or nearly perfect spin polarized electric current, namely a spin current. Since it allows defining the spin direction of electrons to propagate by controlling the direction of magnetization in the

magnetic atom thin film, there is also realized a spin switching device for switching a spin current between states of conduction and nonconduction. Further, using the fact that the magnetic atom thin film externally controlled and thereby brought into a state of magnetization holds that state until a next control is effected thereon, there is realized a spin memory device that can operate to write information on controlling the direction of magnetization of the magnetic atom thin film and to read information on detecting the state of conduction or nonconduction for a spin current.

Also, constructed by a system of a solid surface and a magnetic atom thin film layered thereon, the device can confine a spin current into an extremely small space and, as a result, can be made extremely small.

Further, since the switching or memory writing is confined into the microfine area and is performed by magnetizing normally and reversely the magnetic atom thin film of one to several atomic layer thickness, an ultimate energy saving performance is also achieved.

Consequently, there is provided in accordance with the present invention a device that can be implemented as a spin conducting, a spin switching and a spin memory device in the spintronics and also as a magnetoresistance device that is extremely large in resistance change.

[Brief Description of the Drawings]

Fig. 1 shows a graph illustrating a structure of an electronic state band of copper (111) surface;

Fig. 2 is a graph illustrating an electronic state band structure of a system of Cu (111) surface having a Fe monoatomic layer laid thereon;

Fig. 3 is a view illustrating the makeup of a surface-spintronic spin conductive device according to the present invention;

Fig. 4 is a view illustrating the makeup of a surface-spintronic spin switching device according to the present invention and having a first mechanism of magnetization switching means;

Fig. 5 shows diagrams illustrating principles of reverse

magnetization switching in the first mechanism of magnetization switching means; and

Fig. 6 is a view illustrating the makeup of a surface-spintronic spin switching device according to the present invention and having a second mechanism of magnetization switching means.

[Explanation of Marks and Symbols]

10	Surface-spintronic spin conductive device
11	Substrate
12	Solid crystal
13	Magnetic atom thin film
14	Drain electrode
15	Source electrode
16, 17	Surface-spintronic spin switching device
21, 22	Electric supply line
23	Electric supply
24, 25	Switch
31, 32	Spin source
33	Electric supply
34, 35	Switch

[Name of Document] Abstract
[Abstract]
[Problem] A spintronic device operating on a novel principle of operation is offered as a spin conducting, a spin switching and a spin memory device.
[Means to Solve Problems] It includes a magnetic atom thin film 13 layered on a surface of a solid crystal 12 and a drain and a source electrodes 14 and 15 disposed at two locations on the magnetic atom thin film, respectively, whereby a spin splitting surface electronic state band formed in a system comprising said solid crystal 12 surface and said magnetic atom thin film 13 is utilized to obtain a spin polarized current flow. With electrons spin-polarized in a particular direction injected beforehand from the source electrode 15, controlling the direction of magnetization of the magnetic atom thin film 13 allows switching on and off the conduction of such injected electrons therethrough. With the use of the magnetization holding function of the magnetic atom thin film 13, it is possible to realize a spin memory device that can operate to write information on controlling the direction of magnetization of the magnetic atom thin film 13 and that can operate to read information on detecting the state of conduction or nonconduction between the source and drain electrodes 15 and 14.